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The dissociation of molecular ions by an externally applied electric field, E, or an equivalent electric field, $E' = v \times B$, due to motion through a magnetic field has been calculated by Hiskes.[1] Qualitatively, it is predicted that the external fields warp the nuclear potential in such a way that the higher vibrational states become unstable and dissociation results. This effect has been observed recently by Riviere and Sweetman,[2] who dissociated H_2^+ and H_3^+ ions of approximately 2 Mev energy with electric fields of up to 5×10^5 v/cm. The measurements presented here demonstrate the break-up of molecular hydrogen ions of 10 Mev per nucleon by static magnetic fields.

The experimental arrangement is shown in Fig. 1. Ions produced in a PIG discharge were accelerated in the Berkeley heavy-ion linear accelerator (Hilac). H_2^+ and H_3^+ ions were continuously accelerated to full energy, and, alternatively, full-energy H_2^+ ions were obtained by partially stripping 3-Mev H_3^+ ions in a jet of Hg vapor and then accelerating the resulting H_2^+ ions to 20 Mev. The reason for producing H_2^+ by the latter technique is that such ions might be left in more highly excited states than those which came directly from the ion source, as demonstrated by Riviere and Sweetman. The ions emerged from the Hilac accompanied by other particles formed by break-up on the residual gas in the vacuum system. The beam was collimated to $3/16 \times 3/16$ in., and the various particles were then separated by bending the useful beam by 15 deg in a dc magnetic field. No further collimation was required, thus eliminating background from break-up at slit edges.

The dissociation and analysis were obtained in a dc magnet with a 4-in. gap. The gap in the first 1.5 in. of the magnet could be reduced to 1 in., thereby producing a maximum magnet field of about 19 kilogauss. The beam required about 10^{-9} second to traverse this region.

The results reported here were obtained by activating 0.010-in.-thick Cu foils, placed in the analyzing magnet perpendicular to the direction of the incident beam. The foil holder was built to serve as a Faraday cup, and was used in the beam-monitoring system. The spatial distribution and the relative intensities of the beam particles (i.e., H^0, H_1^+, H_2^+, etc.) were determined by counting the Zn^{63} activity ($T_{1/2}$ = 38 min) produced in the foil.

Briefly, the scanning was done as follows: the bombarded Cu foil was wrapped around a rotating wheel whose instantaneous position was synchronized with the voltage of a linear ramp. A NaI crystal viewed the wheel through a slit in a W and Pb shield. Whenever a 0.51-Mev annihilation γ ray from Zn^{63} decay was detected in the crystal, a pulse of height equal to the ramp voltage was generated. These pulses were put into a Penco 100-channel pulse-height analyzer, and a presentation of count rate vs position on the foil was obtained.

The dissociation caused by the residual gas in the vacuum system at our base pressure of about 6×10^{-6} mm Hg was determined by raising the pressure in several steps by adding N_2, measuring the dissociation, and extrapolating to the base pressure.

The H_2^+ ions obtained by stripping H_3^+ were partially dissociated by the magnetic field, with a rapid rise at about 12 kilogauss. This magnetic field corresponds to approximately 5×10^5 v/cm (Fig. 2). Our result is consistent with the dissociation of the v = 17 vibrational state as calculated by Hiskes for nonrotating molecules. The vertical bands marked 10^{-8} sec and 10^{-14} sec indicate the calculated

fields necessary for barrier penetration in these times, with the widths of the bands corresponding to the uncertainties. The field in the 15-deg bending magnet was sufficiently high to have already dissociated the $v = 18$ vibrational state if it were populated. Conversely, the maximum stripping field was somewhat too low to affect the $v = 16$ state.

No indication of magnetic field dissociation was obtained for the directly accelerated H_2^+ and H_3^+ ions. We have no theoretical information concerning the H_3^+ ion. The absence of dissociation of directly accelerated H_2^+ ions is assumed to be due to the method of formation and to possible de-excitation in the ion source.

With more suitable choices of the kind of ion, energy, and magnetic field strength, dissociation by a magnetic field might provide a mechanism for trapping ions in a highly evacuated controlled thermonuclear device, and provide a diagnostic tool for the study of molecular ion formation and excitation. We are extending this investigation to other molecular ions and to neutral atoms in similar and higher magnetic fields.

We wish to express our appreciation to Dr. C. M. Van Atta for supporting and encouraging this research, J. Warren Stearns and Henry F. Rugge for helping with the measurements, Dr. Edward L. Hubbard, Duane A. Spence, and other members of the Hilac staff, for their assistance, John R. Meneghetti for much of the mechanical construction, and Dr. John R. Hiskes for many interesting and useful theoretical discussions. One of the authors (S. K.) would like to thank Professor Burton J. Moyer for the support and interest that enabled him to participate in this work.

Notes and References

*Work done under the auspices of the U. S. Atomic Energy Commission.

1. J. R. Hiskes, Phys. Rev. 122, 1207 (1961).

2. A. C. Riviere and D. R. Sweetman, Phys. Rev. Letters 5, 560 (1960).

Figure Captions

Fig. 1. Experimental arrangement.

Fig. 2. Fraction of the beam dissociated by magnetic fields (present experiment) and electric fields (Riviere and Sweetman). ▲, magnetic, H_2^+ from H_3^+; ●, magnetic, H_2^+ direct; △, electric, H_2^+ from H_3^+; ○, electric, H_2^+ direct. A background-gas break-up corresponding to a fractional dissociation of $(0.26\pm0.04)\times10^{-3}$ has been substracted from the magnetic dissociation data. The standard deviations shown include counting statistics, an estimated uncertainty of 15% in the extrapolated dissociation by the residual gas in the vacuum system, and an uncertainty of 5% in the calibrations of foil activity vs. ion current.

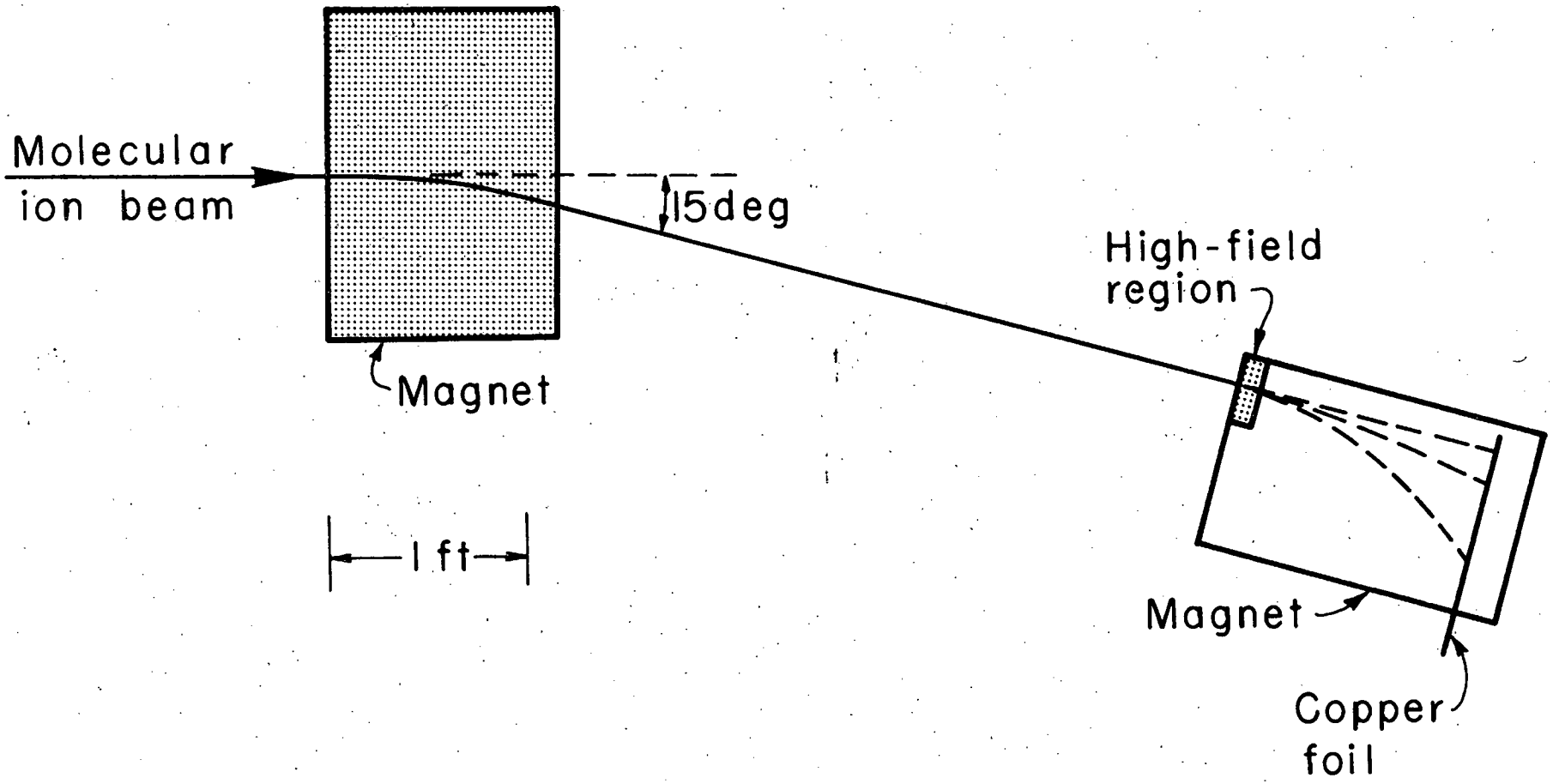

Fig. 1

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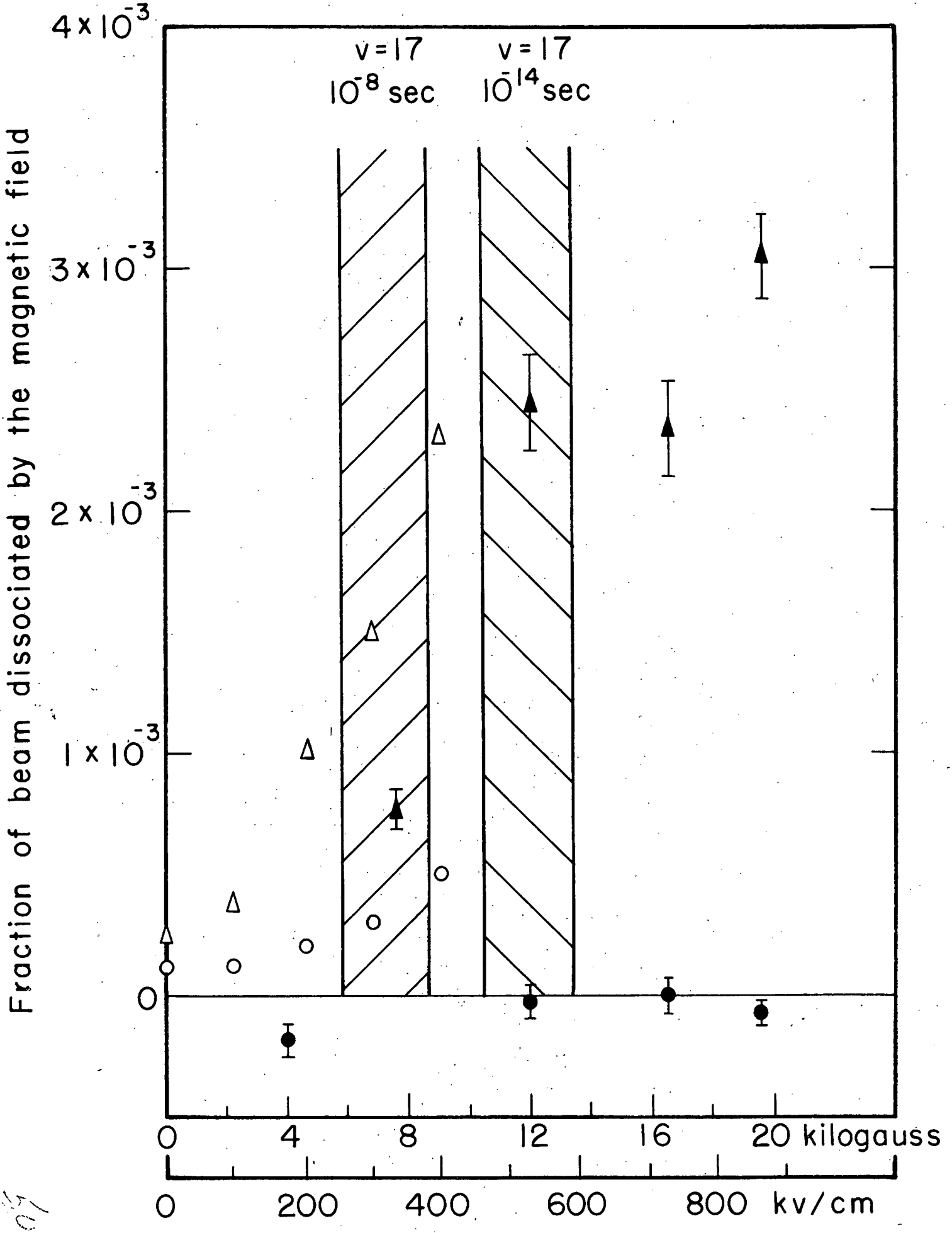
4 x 10^-3
3 x 10^-3
2 x 10^-3
1 x 10^-3
0
v = 17
10^-8 sec
v = 17
10^-14 sec
Fraction of beam dissociated by the magnetic field
0
4
8
12
16
20 kilogauss
0
200
400
600
800 kv/cm

Fig. 2

60 175-1